RANGKAIAN ANALOG

Fajar Budiman

Minggu ke-1

Outline

Materi kuliah minggu-1:

- **Silabus**
- **Referensi**
- **Kontrak kuliah**
- **Mengenal OP-AMP**

Pendahuluan

- Mata kuliah Rangkaian Analog membahas tentang karakteristik rangkaian integrasi penguat operasional, konsep feedback negatif dan positif, rangkaian penguat feedback, komparator, detector level tegangan, hysteresis, rangkaian pembangkit gelombang persegi, segitiga, gigi gergaji, osilator Wien, dan komputer analog, integrator, diferensiator, serta filter aktif Butterworth LPF, HPF, BPF, dan BSF yang diimplementasikan pada penguat operasional

Pokok Bahasan:

- Karakteristik dasar rangkaian integrasi penguat operasional
- Amplifier: Inverting, Non-inverting, adder, buffer, diferensial, dan instrumentasi,
- Komparator: open loop (zero crossing detector), feedback posiitif (dengan atau tanpa hysteresis)
- Signal generator dan osilator Wien
- Filter aktif Butterworth (LPF, HPF, BPF, BSF)
- Parameter Op-Amp

Objectives

- Menguasai teori dan karakteristik rangkaian integrasi penguat operasiona
- Menguasai konsep rangkaian analog feedback negatif khususnya pada penguat operasional
- Menguasai analisa rangkaian feedback positif pada penguat operasional
- Menguasai prinsip kerja rangkaian pembangkit sinyal dan osilator pada penguat operasional
- Menguasai analisa dan disain filter aktif Butterworth pada penguat operasional
- Menguasai parameter operasional amplifier

Buku referensi

- Diktat Kuliah Rangkaian Analog, Hendra Kusuma 2018
- Robert F Coughlin, Frederick F Driscoll, Operational Amplifier and Linear Integrated Circuit, Prentice-Hall International, 2001.
- James M. Fiore, Operational Amplifiers & Linear Integrated Circuits: Theory and Application, 2016
- Ramakant A Gayakward, Op-Amp dan Linear Integrated Circuits, Prentice-Hall, 2000.
- Pujiono, Rangkaian Elektronika Analog, Graha Ilmu: 2012.

Kontrak Kuliah

- Tugas 1 sd Tugas 4 = 20%
- Kuis: Evaluasi 1 dan 3 = 30%
- ETS (Evaluasi 2) = 25%
- EAS (Evaluasi 4) = 25%
- Kehadiran minimal 81% dari 14 pertemuan

Minggu ke-1

PENGENALAN OPERASIONAL AMPLIFIER

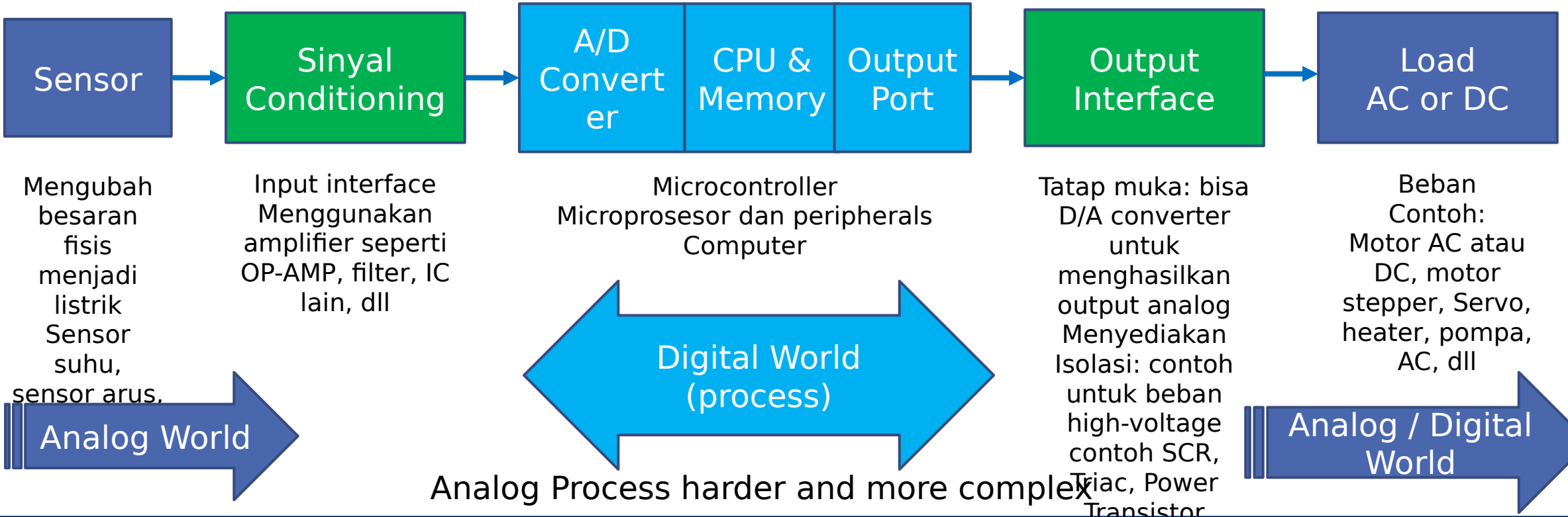
Fajar Budiman

Sistem Analog dan Digital

- Sering dengar “Ini dunia digital”
- Kenapa harus belajar analog?
- Iya betul: sekarang semua dibuat smart dan simpel oleh sistem digital
  - Microcomputer, microcontroller, digital signal processing
- Digital akan lebih berkembang: lebih cepat, akurat dan pengiriman data melalui jaringan contoh tren: AI, IoT dll
- Namun:
- Semakin Sistem digital yang digunakan untuk akuisisi data dan kontrol
- Maka kebutuhan sistem/rangkaian analog untuk interface (tatap muka) atau sinyal konditioner seperti op-amp dan linier IC
- Jadi Kita harus mengerti Sistem Digital dan Analog

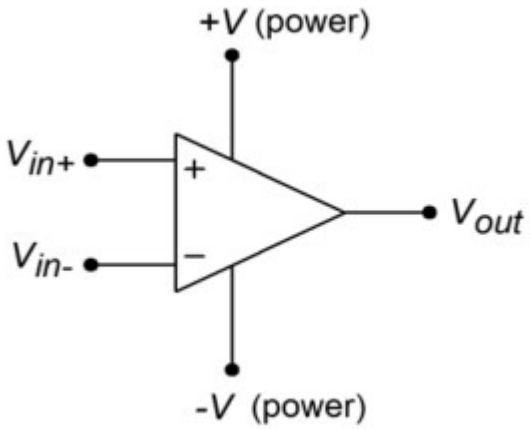
Sistem Analog dan Digital

Typical Data Acquisition

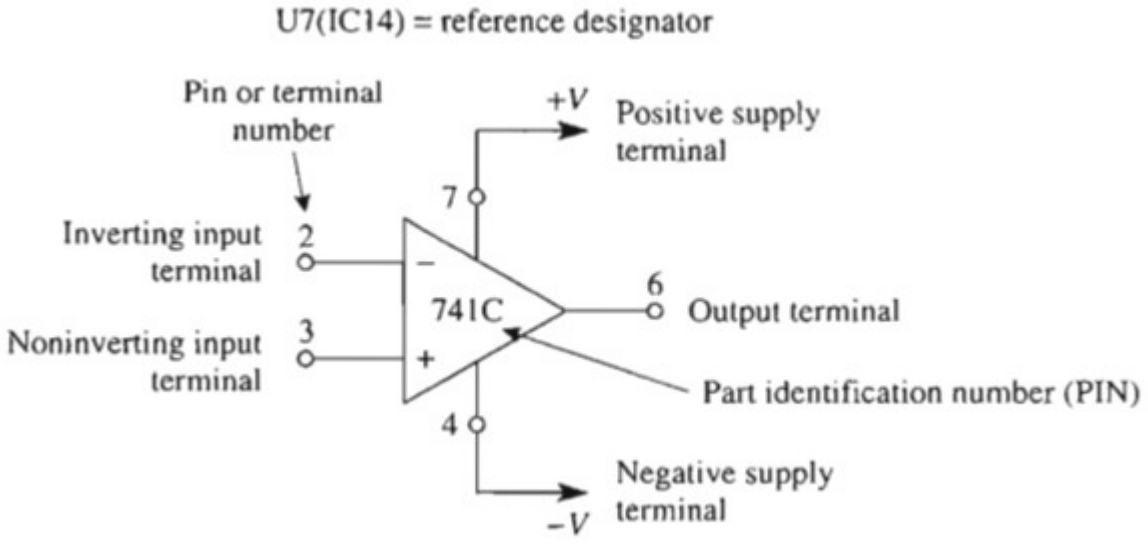

Sensor
Sinyal Conditioning
A/D Converter
CPU & Memory
Output Port
Output Interface
Load AC or DC
Mengubah besaran fisis menjadi listrik Sensor suhu, sensor arus,
Input interface Menggunakan amplifier seperti OP-AMP, filter, IC lain, dll
Microcontroller Microprosesor dan peripherals Computer
Tatap muka: bisa D/A converter untuk menghasilkan output analog Menyediakan Isolasi: contoh untuk beban high-voltage contoh SCR, Triac, Power Transistor dll
Beban Contoh: Motor AC atau DC, motor stepper, Servo, heater, pompa, AC, dll
Analog World
Digital World (process)
Analog / Digital World
Analog Process harder and more complex

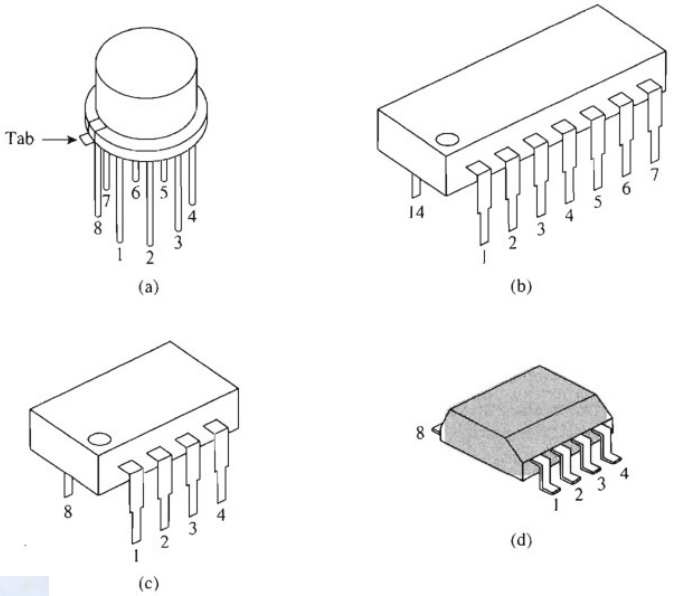
Operational Amplifier (Op-Amp)

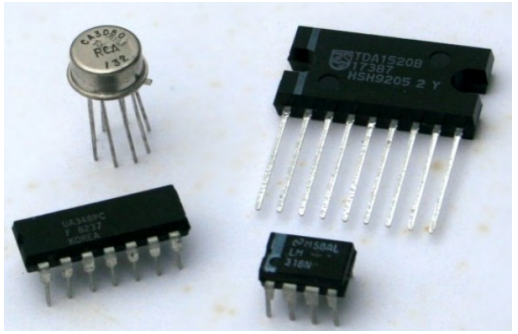
- a multi-stage high gain amplifier treated as a single entity
- a differential input and a single-ended output
- Dibuat dari Transistor Bipolar
  - Bipolar dan MOS (BiMOS) : faster & high frequecy respc



OP-AMP : Block diagram dan package







IC Package (a) Metal can; (b) Dual in Line (d) for High density Surface-Mounted Technology (SMT) or called Surface-Mounted Device (SMD)

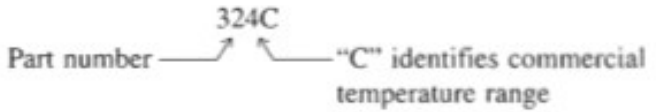
OP-AMP: Mengenal IC

- Op amp tipe apa? Contoh : 741
- Siapa yang membuat? Contoh: Analog Devices
- Seberapa bagus? Contoh: temperature range of operation
- Jenis package houses pada Chip/IC? contoh: plastic DIP

OP-AMP: Mengenal IC (2)

- Letter prefix: dua atau tiga huruf untuk identifikasi manufaktur
- Circuit Designation: 3-7 nomor dan huruf
- Letter suffix: 2-3 huruf, untuk identifikasi package house dari IC
- Kode militer khusus
- Semua ini dan parameter IC lain

Letter prefix	Manufacturer	Manufacturer's Web Site
AD/OP	Analog Devices	www.analog.com
INA/OPA	Burr-Brown	www.burr-brown.com
CD	Cirrus Logic	www.cirrus.com
LF/LT/LTC	Linear Technology	www.linear-tech.com
MAX	Maxim	www.maxim-ic.com
MC	Motorola	www.motorola.com
LF/LM/LMC/LMV	National Semiconductor	www.national.com
TL/TLC/TH/TM	Texas Instruments	www.ti.com



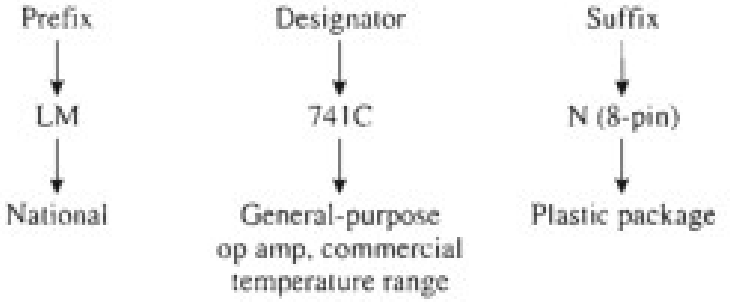
Package code	Description
D	Plastic dual-in-line for surface mounting on a pc board
J	Ceramic dual-in-line
N, P	Plastic dual-in-line for insertion into sockets. (Leads extend through the top surface of a pc board and are soldered to the bottom surface.)

The three *temperature-range codes* are as follows:

1. C: commercial, 0 to 70°C
2. I: industrial, −25 to 85°C
3. M: military, −55 to 125°C

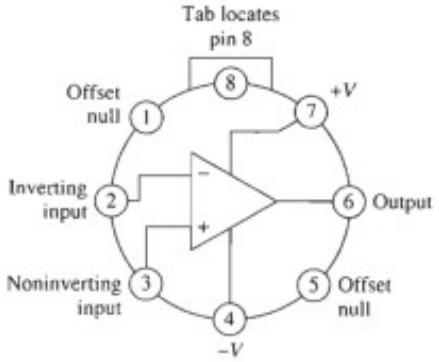
OP-AMP: Mengenal IC (3)

- Contoh 741:
- Original didesain oleh Fairchild µA741
- 741 banyak difabrikasi oleh banyak manufaktu
  - TL-741,
  - AD741,
  - LM741

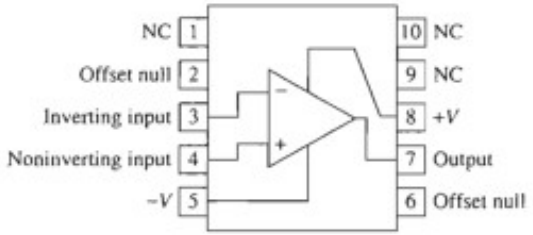


OP-AMP: Simbols dan Pinout

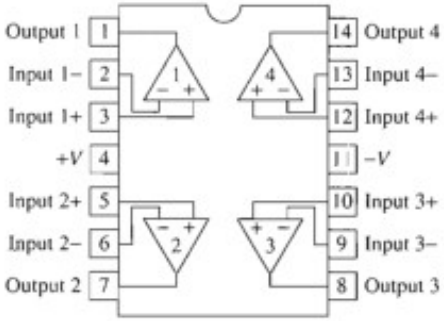
- Contoh 741:



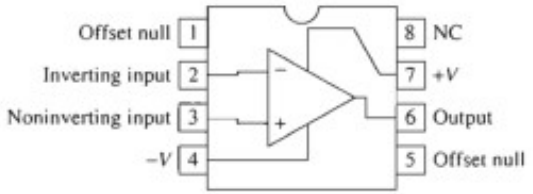
(a) 8-lead metal can (TO-99), top view.



(b) 10-lead flatpack (TO-91), top view.

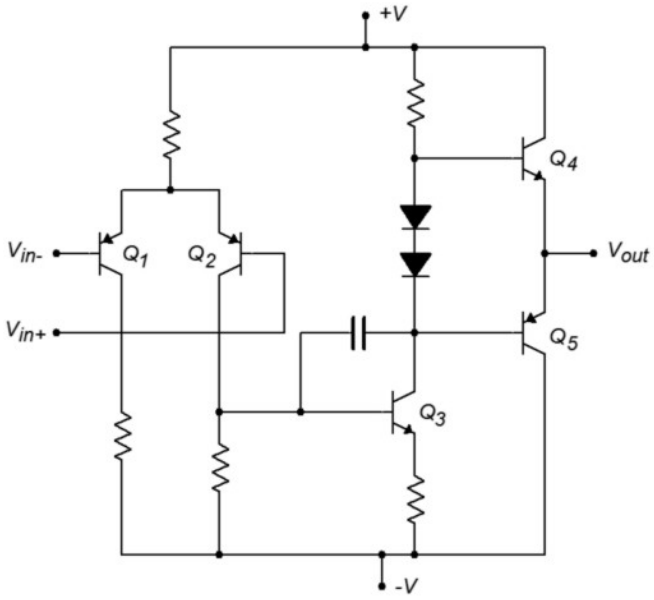


(c) 14-lead dual-in-line package (DIP, TO-116), top view.

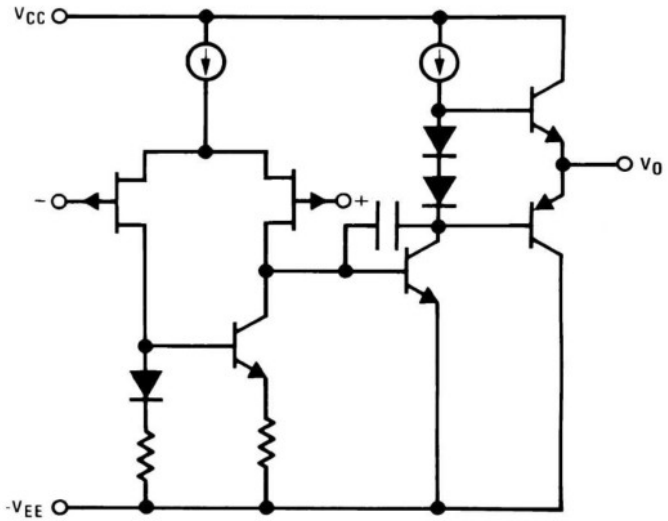


(d) 8-lead mini-DIP top view.

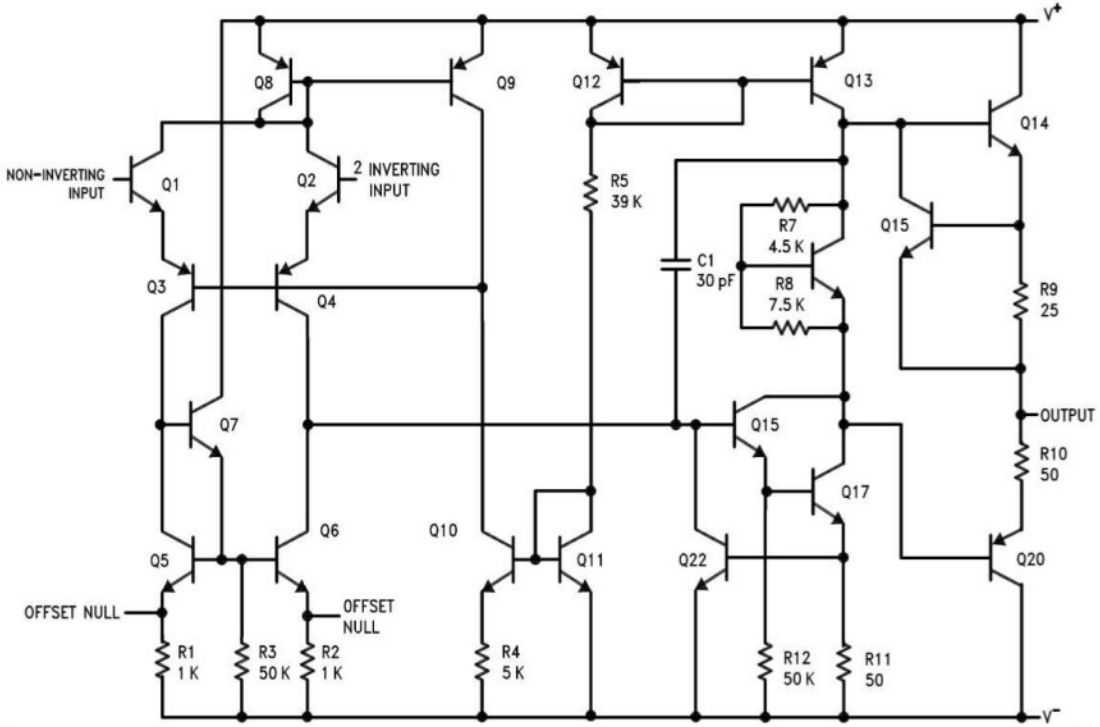
OP-AMP : internal circuit



- General Schematic

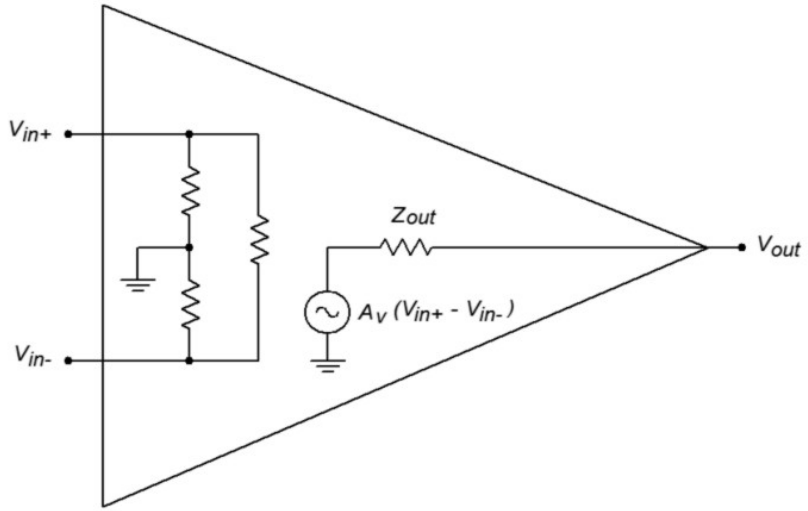


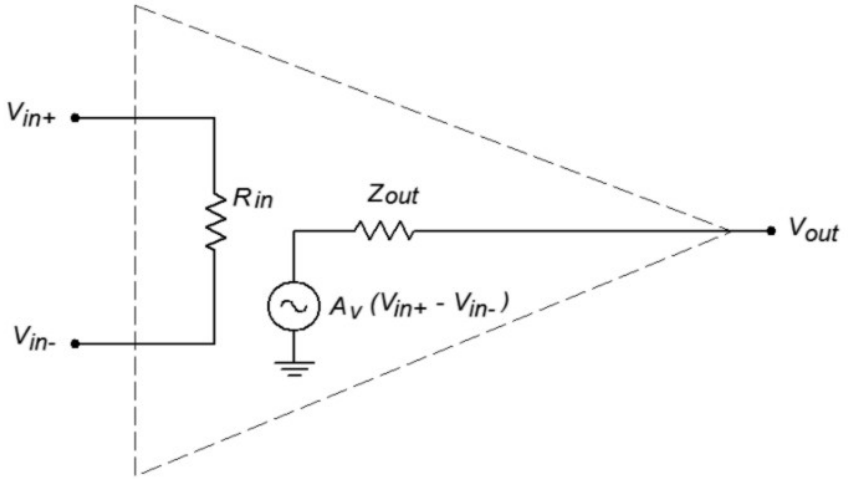
- LF411 Schematic (Simplified)
  Texas Instruments



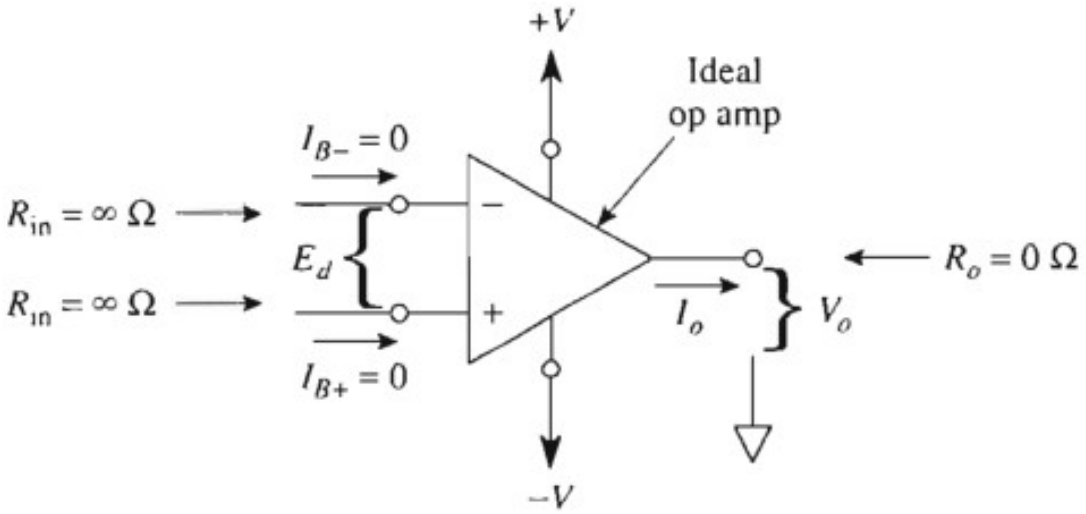
- 741 Schematic

OP-AMP: Simplified Model





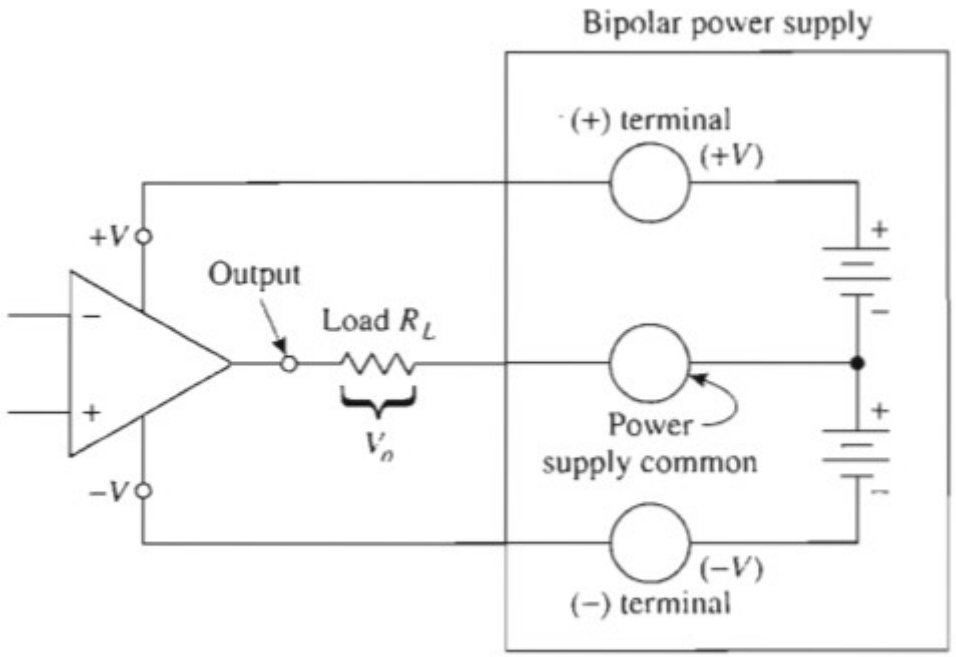
OP-AMP: IDEAL & Terminals



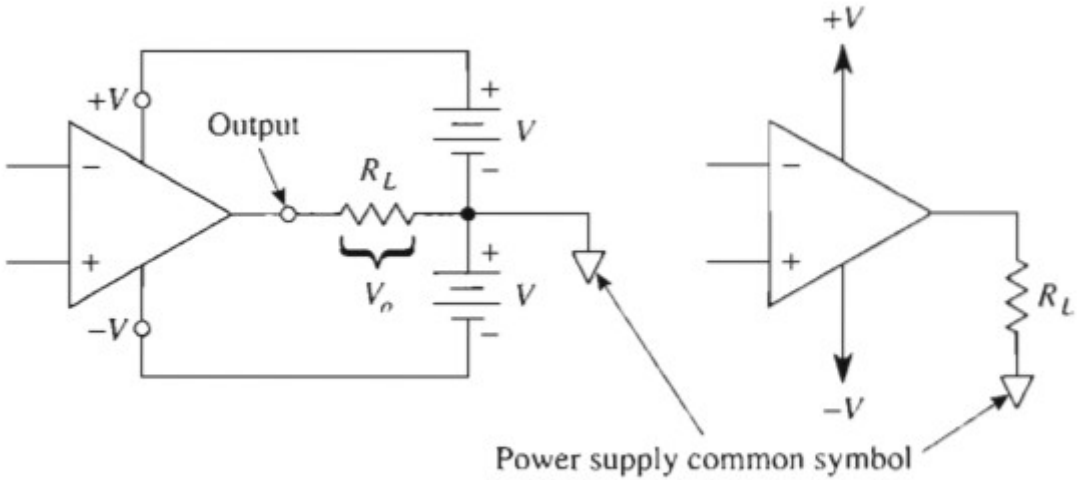
- Ideal OP-AMP

- Gain (Penguatan) = tak hingga
- Resistansi/impedansi
  - Zin = tak hingga
  - Zout = nol

OP-AMP: POWERING



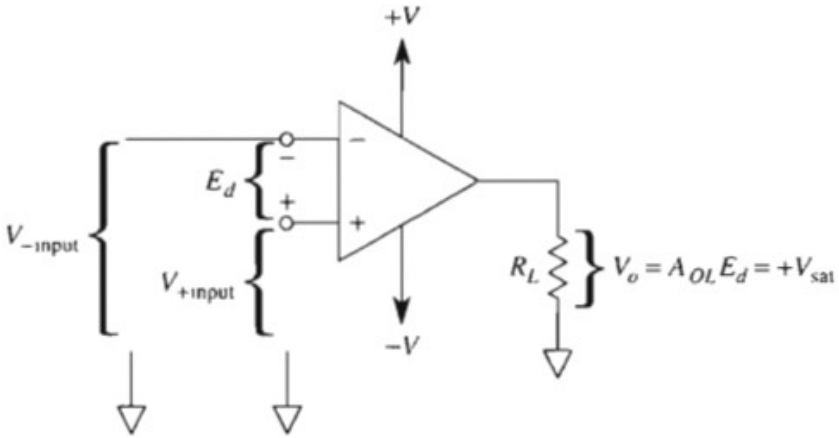
(a) Actual wiring from power supply to op amp.

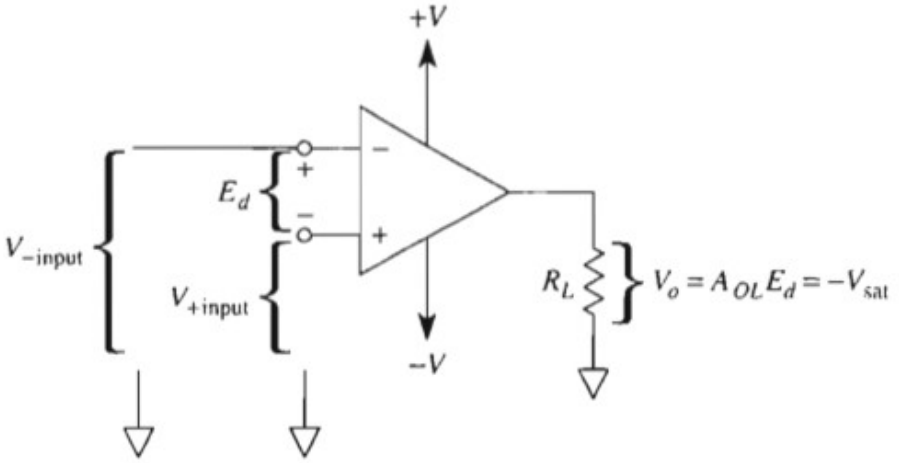


(b) Typical schematic representations of supplying power to an op amp.

OP-AMP: Terminals

- Output Terminal
  - Vo mempunyai limit (saturation)
    - Jika powernya ±15 V -> Vo = ±14 V atau ±13 V
    - Turun ±1 V atau ±2 V
    - Jika powernya V= ±12 V -> V_{sat} = ±10 V
- Input Terminal
  - Disebut differential input
    - Inverting dan non-inverting inputs
  - Tegangan diantara input disebut Ed
  - Ed = + maka Vo = +Vsat
  - Ed = - maka V0 = -Vsat
- Input bias currents and Offset Voltage
  - Dibahas nanti di bab parameter op-amp





OP-AMP: Open Loop Gain

- Output voltage = differential input X open-loop gain
- $V_o = E_d$ X A_{OL}
- Contoh F411 atau LM741
  - A_{OL} = 200.000
  - Contoh: Supply ±V= ±15V maka ±Vo (sat) = ±13

$$E_{d\,\max} = \frac{+V_{sat}}{A_{OL}} = \frac{13\ \text{V}}{200{,}000} = 65\ \mu\text{V}$$

$$-E_{d\,\max} = \frac{-V_{sat}}{A_{OL}} = \frac{-13\ \text{V}}{200{,}000} = -65\ \mu\text{V}$$

Tegangan Ed ini disebut offset

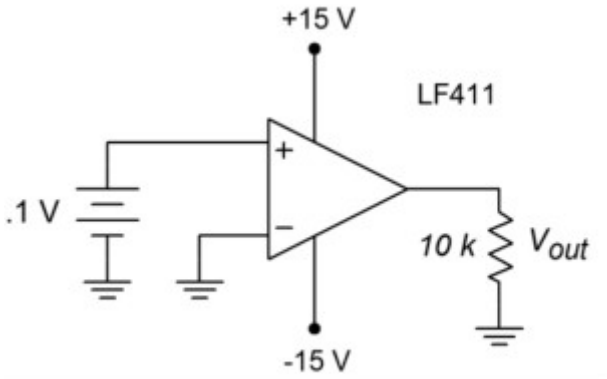
Contoh

- V= ±15 V dan V_{sat} = ±13 V; A_{OL} = 200.000, Tentukan
- Jawaban:

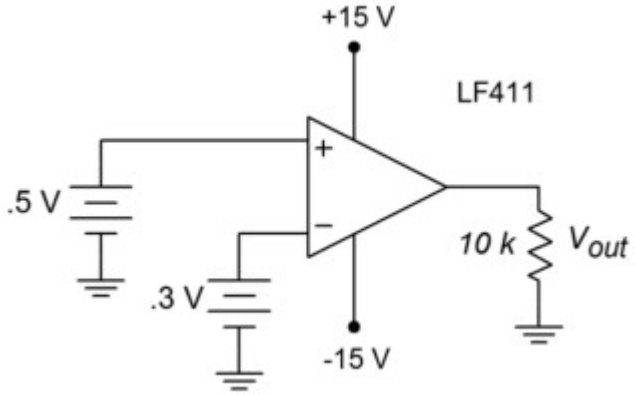
	Voltage at (−) input	Voltage at (+) input
(a)	−10 μV	−15 μV
(b)	−10 μV	+15 μV
(c)	−10 μV	−5 μV
(d)	+1.000001 V	+1.000000 V
(e)	+5 mV	0 V
(f)	0 V	+5 mV

	E_d [using Eq. (2-1)]	Polarity of (+) input with respect to (−) input	Theoretical V_o [from Eq. (2-2)]	Actual V_o
(a)	−5 μV	−	−5 μV × 200,000 = −1.0 V	−13 V
(b)	25 μV	+	25 μV × 200,000 = 5.0 V	+13 V
(c)	5 μV	+	5 μV × 200,000 = 1.0 V	+13 V
(d)	−1 μV	−	−1 μV × 200,000 = −0.2 V	−13 V
(e)	−5 mV	−	−5 mV × 200,000 = −1000 V	−13 V
(f)	5 mV	+	5 mV × 200,000 = 1000 V	+13 V

OP-AMP : Zero Crossing Detector (Simple Comparator)

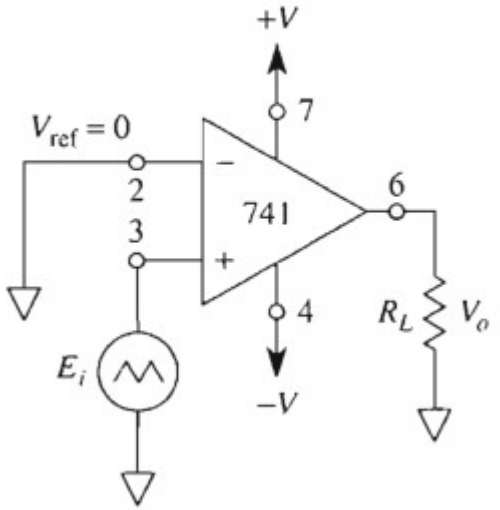


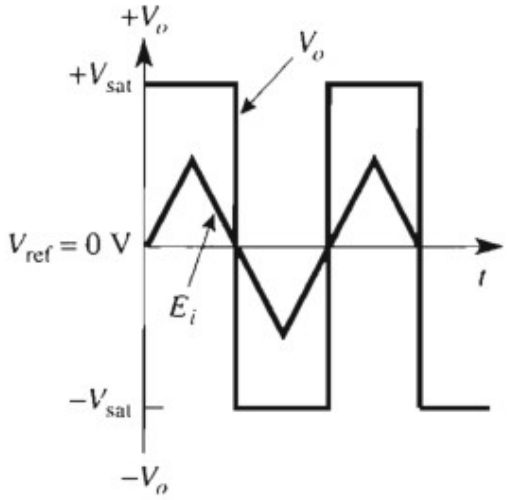
$$V_{out} = A_{vol}(V_{in+} - V_{in-})$$
$$V_{out} = 200{,}000 \times (.1\,\text{V} - 0\,\text{V})$$
$$V_{out} = 20{,}000\,\text{V}$$

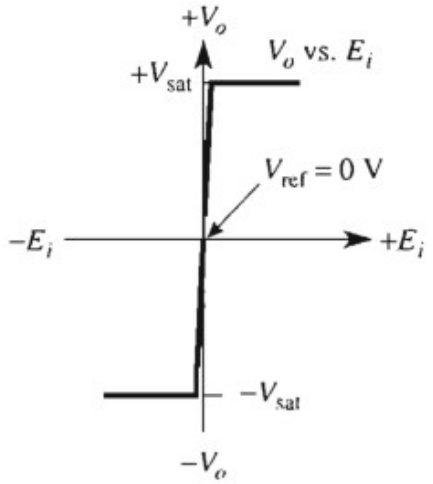


$$V_{out} = A_{vol}(V_{in+} - V_{in-})$$
$$V_{out} = 200{,}000 \times (.5\,\text{V} - .3\,\text{V})$$
$$V_{out} = 40{,}000\,\text{V}$$
$$V_{out} = 13.5\,\text{V, due to clipping}$$

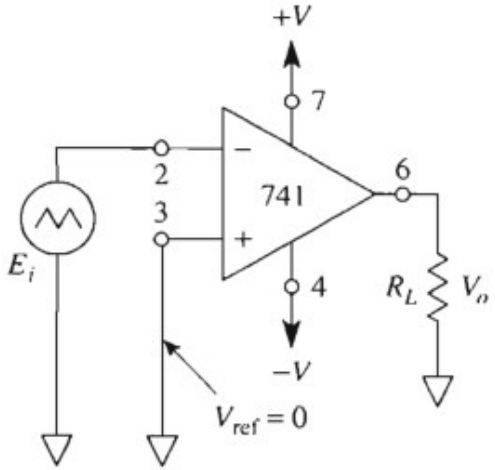
OP-AMP : Zero Crossing Detector (Simple Comparator)

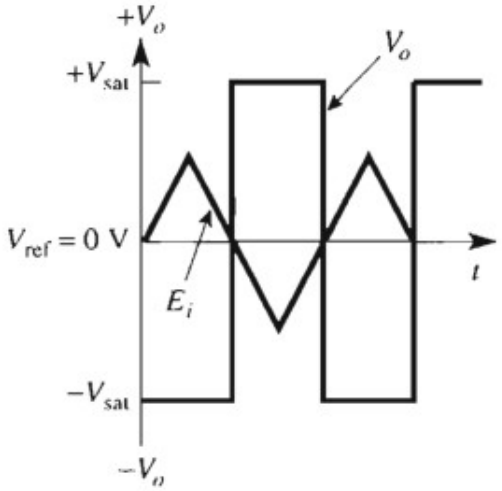


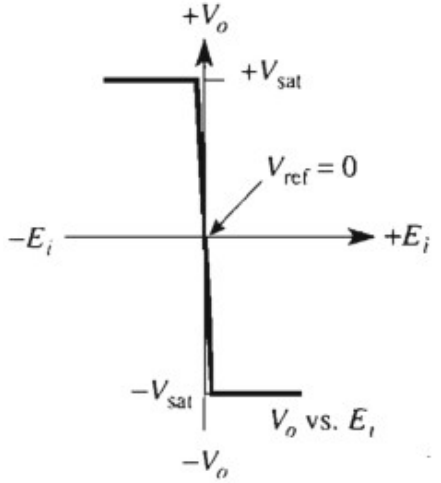




- Non-Inverting Zero Crossing Detector







- Inverting Zero Crossing Detector

OP-AMP: Datasheet (1)

- Membaca Datasheet
- Contoh LF411: (Texas Instrument)

6 Specifications

6.1 Absolute Maximum Ratings[1]

	LF411A		LF411		UNIT
	MIN	MAX	MIN	MAX	
Supply Voltage		±22		±18	V
Differential Input Voltage		±38		±30	V
Input Voltage Range[2]		±19		±15	V
Output Short Circuit Duration		Continuous		Continuous	

	TO Package		PDIP Package		UNIT
	MIN	MAX	MIN	MAX	
Power Dissipation[3] [4]		670		670	mW
$T_j$max		150		115	°C
Operating Temperature		See [5]		See [5]	
Lead Temperature (Soldering, 10 s)		260		260	°C

(1) "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for

6.2 Handling Ratings

		MIN	MAX	UNIT
T_{stg}	Storage temperature range	−65	150	°C

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

	MIN	NOM	MAX	UNIT
Supply Voltage LF411A			±20	V
Supply Voltage LF411			±15	V

OP-AMP: Datashee

- The parameter symbol.
- The parameter name.
- The conditions under which the parameter is measured.
- The parameter values, either typical or min/max.
- The parameter units.

6.5 DC Electrical Characteristics [1][2]

PARAMETER		TEST CONDITIONS		LF411A MIN	LF411A TYP	LF411A MAX	LF411 MIN	LF411 TYP	LF411 MAX	UNIT
V_{OS}	Input Offset Voltage	R_S=10 kΩ, T_A=25°C			0.3	0.5		0.8	2.0	mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	R_S=10 kΩ			7			7		µV/°C
I_{OS}	Input Offset Current	V_S=±15V [2] [3]	T_j=25°C		25	100		25	100	pA
			T_j=70°C			2			2	nA
			T_j=125°C			25			25	nA
I_B	Input Bias Current	V_S=±15V [2] [3]	T_j=25°C		50	200		50	200	pA
			T_j=70°C			4			4	nA
			T_j=125°C			50			50	nA
R_{IN}	Input Resistance	T_j=25°C			10^{12}			10^{12}		Ω
A_{VOL}	Large Signal Voltage Gain	V_S=±15V, V_O=±10V, R_L=2k, T_A=25°C		50	200		25	200		V/mV
		Over Temperature		25	200		15	200		V/mV
V_O	Output Voltage Swing	V_S=±15V, R_L=10k		±12	±13.5		±12	±13.5		V
V_{CM}	Input Common-Mode Voltage Range			±16	+19.5		±11	+14.5		V
					−16.5			−11.5		V
CMRR	Common-Mode Rejection Ratio	R_S≤10k		80	100		70	100		dB
PSRR	Supply Voltage Rejection Ratio	See [4]		80	100		70	100		dB
I_S	Supply Current				1.8	2.8		1.8	3.4	mA

(1) RETS 411X for LF411MH and LF411MJ military specifications.
(2) Unless otherwise specified, the specifications apply over the full temperature range and for V_S=±20V for the LF411A and for V_S=±15V for the LF411. V_{OS}, I_B, and I_{OS} are measured at V_{CM}=0.
(3) The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature, T_j. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation, P_D. T_j=T_A+θ_{jA} P_D where θ_{jA} is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.
(4) Supply voltage rejection ratio is measured for both supply magnitudes increasing or decreasing simultaneously in accordance with common practice, from ±15V to ±5V for the LF411 and from ±20V to ±5V for the LF411A.

6.6 AC Electrical Characteristics

PARAMETER [1][2]		TEST CONDITIONS	LF411A MIN	LF411A TYP	LF411A MAX	LF411 MIN	LF411 TYP	LF411 MAX	UNIT
SR	Slew Rate	V_S=±15V, T_A=25°C	10	15		8	15		V/µs
GBW	Gain-Bandwidth Product	V_S=±15V, T_A=25°C	3	4		2.7	4		MHz
e_n	Equivalent Input Noise Voltage	T_A=25°C, R_S=100Ω, f=1 kHz		25			25		nV / √Hz
i_n	Equivalent Input Noise Current	T_A=25°C, f=1 kHz		0.01			0.01		pA / √Hz
THD	Total Harmonic Distortion	A_V=+10, R_L=10k, V_O=20 Vp-p, BW=20 Hz-20 kHz		<0.02 %			<0.02 %		

(1) Unless otherwise specified, the specifications apply over the full temperature range and for V_S=±20V for the LF411A and for V_S=±15V for the LF411. V_{OS}, I_B, and I_{OS} are measured at V_{CM}=0.
(2) RETS 411X for LF411MH and LF411MJ military specifications.

6.6 AC Electrical Characteristics

PARAMETER [1][2]		TEST CONDITIONS	LF411A MIN	LF411A TYP	LF411A MAX	LF411 MIN	LF411 TYP	LF411 MAX	UNIT
SR	Slew Rate	V_S=±15V, T_A=25°C	10	15		8	15		V/µs
GBW	Gain-Bandwidth Product	V_S=±15V, T_A=25°C	3	4		2.7	4		MHz
e_n	Equivalent Input Noise Voltage	T_A=25°C, R_S=100Ω, f=1 kHz		25			25		nV / √Hz
i_n	Equivalent Input Noise Current	T_A=25°C, f=1 kHz		0.01			0.01		pA / √Hz
THD	Total Harmonic Distortion	A_V=+10, R_L=10k, V_O=20 Vp-p, BW=20 Hz-20 kHz		<0.02 %			<0.02 %		

(1) Unless otherwise specified, the specifications apply over the full temperature range and for V_S=±20V for the LF411A and for V_S=±15V for the LF411. V_{OS}, I_B, and I_{OS} are measured at V_{CM}=0.
(2) RETS 411X for LF411MH and LF411MJ military specifications.

Tugas

- Cari IC OP-AMP beserta DATASHEET minimal 5 secara online
- Verifikasi dan jelaskan parameternya.

Minggu ke-1

TERIMA KASIH

Fajar Budiman